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NEXT GENERATION BARE BASE WASTE PROCESSING SYSTEM (PHASE I)

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14. ABSTRACT

Georgia Tech conducted an engineering analysis which examined the existing Bare Base waste systems support infrastructure documentation. The initial phase of this study focused on identifying the waste source, types and quantites of the existing Bare Base; other forseeable operational considerations which could potentially impact any prospective integrated waste treatment system for future USAF Bare Base operations were also examined. Major deliverables in this report include a quantification and qualification of existing Bare Base waste systems infrastructure to expedite development (Phase II) and system demonstration (Phase III) of an integrated waste treatment system for future USAF Bare Base operations.

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Dr. Rita Gregory, School of Civil and Environmental Engineering, provided additional technical expertise regarding Bare Base waste generation and previous studies conducted.

Major participants in this research program and the principal authors of this report are as follows:

Dr. Louis J. Circeo, Director, CRC was the Program Manager and Principal Investigator for the research program.

Mr. John Pierson, Research Engineer II, was the GTRI Project Director for this research program.

Mr. Robert Lewallyn, Research Engineer I, and **Mr. Robert Newsom**, Senior Research Technologist, contributed material related to solid (non-hazardous and hazardous) waste generation and solid waste technologies, respectively.

Mr. Nick Jenkins, graduate assistant, conducted the initial Bare Base waste collection system review. His efforts provided the base line information used for the Georgia Tech assessment, and his summer research contributions greatly stream lined the Georgia Tech effort by providing a sound point of departure.

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EXECUTIVE SUMMARY

Extensive deployment of Harvest Falcon kits in the 1991 Gulf War revealed numerous opportunities for improvements in reliability, transportability, ease of installation, and waste management, among other factors. The Gulf War highlighted the degree to which many Bare Base elements had become antiquated in comparison to new and emerging technologies. Current Military Operations Other Than War (MOOTW) taskings also demonstrate that equipment used in Bare Base operations may not be necessarily dedicated for use only during Bare Base deployments. The USAF has aggressively moved to address these issues.

Georgia Tech conducted an engineering analysis which examined the existing Bare Base waste systems support infrastructure documentation. The initial phase of this study focused on identifying the waste source, types and quantities of the existing Bare Base; other foreseeable operational considerations which could potentially impact any prospective integrated waste treatment system for future USAF Bare Base operations were also examined. Major deliverables in this report include a quantification and qualification of existing Bare Base waste systems infrastructure to expedite development (Phase II) and system demonstration (Phase III) of an integrated waste treatment system for future USAF Bare Base operations.

This interim study estimates that 4.4 lbs/person/day of non-hazardous and 0.44 lbs/person/day of hazardous solid waste will be generated by an 1100 person Bare Base deployment for peacekeeping operations. Additionally, wastewater generation is estimated to be 14.0 to 22.3 gallons/person/day, with black water liquid and solids, meals and housekeeping constituting approximately 16.7%, 20.0%, 16.7% and 46.7%, respectively. While no reasonable estimate of medical and biohazardous waste generation rates was found, estimates of the nature and quantity of medical wastes generated were qualitatively concluded to vary significantly, based upon the specific operational tasking.

Bare Base scenarios, ranging from peacekeeping operations comparable to Operation Joint Endeavor, to humanitarian missions, to combat situations such as the Gulf War, will present a diverse solid waste stream. This waste stream will generally be categorized by (1) nonhazardous solid waste; (2) organic/dewatered sanitary solids; (3) hazardous wastes; and (4) medical or biohazardous, and/or nuclear, biological or chemical (NBC) agent residual wastes.

The solid waste volumes associated with each of these categories will vary in magnitude based upon the contingency. Although each waste stream category may be generated regardless of the tactical situation (i.e. large quantities medical or biohazardous wastes could easily be produced due to poor sanitation or epidemics, as well as combat), the volumes produced will more profoundly impact overall Bare Base operational effectiveness as the required treatment progresses from nonhazardous, hazardous and then medical, biohazardous, or NBC generated waste streams. For all Bare Base solid waste streams, the plasma arc technology appears to have the broadest applicability for processing these non-hazardous, hazardous, medical or biohazardous, and NBC generated wastes.

Plasma torches provide the flexibility, diversity, force multiplier, and addressability for future operations and contingencies. Mobile, modular systems can be designed to permit resource commitment based upon the dynamic nature of the contingency. Plasma arc technology is also capable of processing all solid waste streams envisioned for a Bare Base deployment. This is especially important based upon the combat/air supply, humanitarian and/or peacekeeping scenarios potentially faced by a Bare Base deployment force. Also, as the tactical situation allowed, processing could then be focused on only the most recalcitrant materials.

Plasma systems provide a force multiplier because of the potential for cogeneration, alternate fuel gases production, and waste heat recovery. These systems compare favorably with regard to manpower, kilowatt usage and heavy equipment requirements of competing technologies. Additionally, hazardous material storage and/or transport can be enhanced or eliminated.

This technology provides the greatest flexibility for the expanding mission requirements and operational environments that Bare Base deployments may experience. Plasma arc technology provides a multiple use potential, i.e. expanded peacetime and Bare Base civil engineering capabilities, such as runway repair, bridge and construction footings. In addition to waste treatment, this technology also generates vitrified material that can be used for aggregates. Finally, plasma arc technology supports current and future environmental policies and direction.

1.0 INTRODUCTION

Georgia Tech was tasked with conducting an engineering analysis of existing Bare Base waste streams, systems, and equipment (Phase 1) to support development (Phase 2) and system demonstration (Phase 3) of an integrated waste treatment system for future USAF Bare Base operations. Phase 1 of this study focused on summarizing existing Bare Base waste processing systems and related waste systems support infrastructure. The Phase 1 analysis expanded upon work conducted by Sverdrup Technology, Inc. (1996) to provide continuity between efforts and to ensure Phases 2 and 3 of this overall effort were based upon work conducted for other Bare Base utilities and facilities analysis.

The interim report reviews relevant work to date on Bare Base infrastructure improvements related to wastewater and solid waste treatment technologies for a typical 1100-person deployment to establish the scope of the study. Existing Bare Base waste streams, with sources identified, characterized and categorized by level of hazard are quantified or qualified to comparatively evaluate Bare Base waste treatment technologies that are either available or expected to reach market in the near term.

This document supports not only the conceptual design development and system demonstration of an integrated waste treatment system for future USAF Bare Base operations, but also integrates environmental policy implications into selection criteria. Sections are summarized to provide an overview, but detail is also provided to document the approach taken to meet required tasks.

2.0 BACKGROUND

Ongoing changes in world economic and political systems have forced extensive re-thinking of the mission and structure of the armed forces of the United States. With the dissolution of the Soviet Union and sweeping democratization of Russia and its former Warsaw Pact allies, U.S. forces have seen their primary concerns, such as a nuclear strike against the United States and a massive invasion of western Europe, almost disappear overnight. In the "new" world, it is far more likely that U.S. forces will be called upon to quickly counter situations in the Third World, or even to engage in Military Operations Other Than War (MOOTW) including refugee evacuation or supervision of elections. Such operations place a premium upon the ability to rapidly deploy manpower and equipment worldwide, regardless of location and with minimal reliance upon pre-existing infrastructure.

In response to its roles as the nation's primary source for global air power and sole provider of heavy airlift, the U.S. Air Force has sought for some time to improve its capability for operating from austere "bare base" facilities. Such efforts date back to the Grey Eagle packages created in the 1950s by repackaging Army tents and utilities to create a modular housekeeping kit. The current USAF Bare Base kit, Harvest Falcon, grew out of experiences in Southwest Asia

in the 1970s. Created in the early 1980s, Harvest Falcon is designed to support 1100-person deployments operating combat aircraft.

Extensive deployment of Harvest Falcon kits in the 1991 Gulf War revealed numerous opportunities for improvements in reliability, transportability, ease of installation, and waste management, among other factors. In particular, Gulf War experience highlighted the degree to which many elements of the Bare Base kits had become antiquated in comparison to commercially available equipment and technologies. Current MOOTW taskings also demonstrate that Bare Base operational equipment may not be necessarily dedicated for use only during Bare Base deployments. The USAF has aggressively moved to address these issues.

The USAF tasked Sverdrup Technology, Inc. with defining promising technologies, available from years 1996 to 2015, for improving current 1100-person+ Bare Bases equipped with austere utility and facility equipment. The Sverdrup study took a systems approach to the Bare Base by considering the interaction among the utility and facility systems. This approach attempted to satisfy user-prioritized and study-amended requirements to determine optimum combinations of characteristics and specific equipment requirements. Sverdrup's strategy was to benchmark the existing Bare Base system by reviewing USAF requirements, evaluating current and near-term technologies to meet these requirements, and then evaluating, ranking and reporting options developed.

Sverdrup (1996) defined the existing Bare Base by identifying the numbers and kinds of equipment, the functional purpose (electricity, clean water, treated waste) of that equipment, and the characteristics of the equipment (weight, cost, survivability) identified as important to the user. Based upon this definition, Sverdrup mapped technologies based upon the user's view of the Bare Base deficiencies and needs. Seven priorities for immediate action were identified, and of these seven priorities, waste water, solid waste and water treatment capabilities were highlighted. Sverdrup (1996) listed waste sources, types, and quantities as among the most pressing directions for further study.

3.0 SCOPE

Phase 1 of this study addresses the deficiencies identified by Sverdrup by focusing on detailing the waste source, types and quantities of the existing bare base and other foreseeable operational considerations which could potentially impact any future integrated waste treatment system for future USAF Bare Base operations. Waste streams characterized included solid, liquid and biohazardous wastes generated by a typical 1100-person deployment. Operational areas included medical, transportation and flight line activities. In general, all wastes generated by Bare Base utilities, facilities and operational activities were evaluated, including wastes potentially derived from material contaminated chemical or biological agents; these wastes may be particularly problematic given the high level priority threat in the Middle East or Korean area of operations.

3.1 Trends Affecting Future Bare Base Waste Systems

Three major outcomes of the Sverdrup study (1996) affect the current work. First, the review of existing Bare Base systems deficiencies and operational requirements, based upon USAF civil engineer and requirement representatives input provides a framework for analysis of waste sources, types and quantities. As stated in the Sverdrup study, properly identifying alternatives to current Bare Base systems requires recognizing criteria for evaluating the tradeoffs associated with viable options. The Sverdrup approach provides the basis to evaluate all utility and facility equipment considerations, including those associated with hazardous and non-hazardous wastes generated at the Bare Base. Following this approach ensures that Phase 1 assessments and recommendations will support the overall analysis of Bare Base utilities and facilities.

A second relevant recommendation suggests that any Bare Base waste assessment should be addressed as an integrated problem with the water treatment and distribution system. Sverdrup (1996) stated that optimal long term solution for waste treatment critically depended on characterizing the waste streams, investigating and proving-out the rapidly moving technologies in waste treatment, and taking advantage of process changes to reduce, reuse and recycle wastes at the source. Phase 1 objectives of this study directly address these issues.

A third consideration, although not explicitly stated, is to ensure alternatives are measured against relevant environmental policies regarding clean water, air and hazardous waste. As the USAF continues to incorporate environmental stewardship into all facets of its operations, meeting or exceeding environmental mandates will continue to impact Bare Base utilities and facilities decisions.

3.2 Tasking

The specific tasks included in this study are:

(1) **Quantify and qualify the existing Bare Base waste (BBW) stream.** All solid, liquid, and biohazardous wastes generated by a typical 1100-person deployment shall be source identified, characterized, and categorized by level of hazard. Current treatment practices shall be addressed for each waste category. Average hourly and daily waste generation volumes for each waste type shall be determined identifying minimum and maximum loading conditions for each.

(2) **Quantify and qualify the existing BBW systems and equipment.** All solid, liquid, and bio-hazardous waste recovery, pre-treatment containment, treatment, post-treatment containment, and/or disposal needed to supply a typical 1100-person deployment kit shall be identified and evaluated. Weight, volume, power requirements, maintenance, and reliability shall be assessed. Existing equipment and material, cost, storage, airlift, and reconstitution requirements shall be addressed.

(3) **Quantify and qualify the existing BBW systems operational guidelines, personnel, and interrelated infrastructure elements**. Current logistics, manpower, and site layout(s) shall be evaluated. Operational guidelines and procedures for the handling of all solid, liquid and biohazardous waste during recovery, pre-treatment containment and/or disposal for a typical 1100-person deployment shall be addressed. Infrastructure capabilities providing support to existing waste processing systems shall be assessed (i.e. generated power available, water demand, etc.).

(4) **Quantify and qualify the existing BBW systems deployment contingencies**. Existing waste systems deployment contingencies shall be assessed per mission (i.e., combat flight, humanitarian, peacekeeping, etc.) and operational environment (i.e., climate, geography, etc.). Significant deviations in types and volumes of generated wastes, as well as required recovery, pre-treatment containment, treatment, post-treatment containment, and/or disposal, shall be assessed.

(5) **Prepare Interim Technical Report**. An interim technical report shall be prepared summarizing all findings from Phase I assessments of existing bare base waste processing systems and related waste systems support infrastructure.

4.0 APPROACH

Sverdrup (1996) developed a systems approach based upon Bare Base systems deficiencies, along with user and operational requirements, and then examined the existing Bare Base waste system. The Phase I assessments of existing Bare Base waste processing systems and related waste systems support infrastructure were designed to leverage this previous work.

Sverdrup BBW study assumptions were examined and greater detail was added, with emphasis on identifying, characterizing and categorizing waste streams sources by level of hazard. Current Bare Base waste systems and equipment were then identified and addressed (section 6) in terms of the system level requirement criteria outlined in the Statement of Work. Operational guidelines, personnel, and inter-related infrastructure elements were included to address overall Bare Base utilities and facilities integration. Waste treatment technologies that are either available or which are expected in the near term were assessed for potential applicability (section 7). Finally, Bare Base waste system deployment contingencies were addressed (section 8) to consider significant deviations in types and volumes of generated wastes and resulting waste disposal implications. Section 9 summarizes the findings from the Phase 1 study by assessing existing Bare Base waste processing systems and related waste systems support infrastructure in terms of promising near and long-term technology candidates.

5.0 QUALIFICATION AND QUANTIFICATION OF EXISTING BARE BASE WASTE STREAMS

Detailing the waste source, types and quantities of the existing and other foreseeable operational considerations required qualifying unknown aspects which could potentially impact any integrated waste treatment system for future USAF Bare Base operations. This qualifying process, coupled with quantification of known waste stream generation rates, was used to estimate the expected daily per capita volume of Bare Base waste streams produced.

5.1 Scope

The Phase I assessment of the existing Bare Base waste stream included: (1) a review of flight line, industrial and housekeeping activities to better characterize potential sources of waste, (2) identification of specific material types to better define potential hazardous and non-hazardous waste streams, and (3) cross referencing of major sources and potential material types. The majority of BBW data were obtained by collecting, identifying and characterizing waste streams based upon observations of field training exercises, analysis of data collected at operational Bare Bases over a three year period, and literature references. Waste generation data from the Brown & Root reports was compared with municipal solid waste (MSW) generation rates reported in contemporary literature. Liquid waste stream estimates were made using generally accepted engineering planning factors taken from literature.

A Silver Flag exercise was observed at Tyndall AFB in July 1996 and observations provided valuable insight into the nature of waste generation in Bare Base operations. Silver Flag is a

five-day exercise conducted to give USAF personnel hands-on experience in establishing a Bare Base. The exercise is conducted by a RED HORSE team (Rapid Engineering Deployable Heavy Operations Repair Squadron Engineer); participants come from other RED HORSE teams, PRIME BEEF units (a scaled-down RED HORSE team), PRIME RIBS (Readiness In Base Services) units, and regular civil engineering units.

Extensive waste generation data gathered from actual deployments proved difficult to obtain, and when available, was often not complete. The bulk of the actual field data was in the form of weekly situation reports generated by Brown & Root Services personnel supporting Operation Joint Endeavor at locations in Bosnia and Hungary; these reports included quantities of waste removed from 30 of the 39 camps supported by the firm. Weekly reports normally specified a daily average values for the quantities of solid waste and liquid waste removed from each site, the numbers of bags of laundry collected and processed, meals served per day, and the site population during the report week. Reports covered 25 March 1996 through 04 May 1996.

5.2 Categories Of Bare Base Waste Streams

Sources of waste generation were expanded from flight line, industrial and housekeeping to include a total of six primary sources: (1) flight line operations; (2) industrial, (including motor pools and mechanical shops); (3) housekeeping, (including personal MSW, mess hall operations, medical, shower and laundry); (4) construction and demolitions; (5) munitions, and (6) others, (including pesticides, herbicides, rodenticides, and fungicides). Table 5.2.1 was qualifies the BBW stream; the six waste generating functions are listed, along with the waste materials generated by each function. Liquid and solid wastes are separated.

Table 5.2.1. Origin of Bare Base Wastes

Source	Liquid	Solid
Flight line Operations[1]	- used engine oil and hydraulic fluid - cleaning solvents	- aircraft tires - metal scrap
Industrial	- used engine oil and antifreeze - sulfuric acid (batteries) - cleaning solvents - used air compressor oil	- vehicle batteries - used oil filters - paint cans - paperboard containers
Housekeeping	- black water (latrines) - grey water (laundry) - grey water (showers) - cleaning solvents	- food preparation - medical waste (bandages) - paperboard containers
Construction and Demolitions[1]	- grey water from washing concrete mixers, mortar pans, etc.	- scrap lumber and PVC pipe & fittings - scrap nails, screws, and other fasteners - paperboard containers
Munitions[1]	- cleaning solvents and waste oil	- spent ammunition casings
Other	- pesticides, herbicides, rodenticides, and fungicides	- spent chemical containers

Note - 1 indicates these operations are contingency dependent

5.3 Quantification of Bare Base Solid Waste Streams

Solid waste streams were divided into non-hazardous and hazardous solid waste, based upon the U.S. Environmental Protection Agency (U.S. EPA) definitions. Medical and biohazardous wastes, while not considered hazardous under U.S. EPA definitions, were segregated from non-hazardous and hazardous solid wastes because generation of biohazardous materials was deemed to be contingency-based. This section quantifies Bare Base solid waste streams.

5.3.1 Non-Hazardous Solid Waste

Initially, the research team planned to evaluate the characterization and quantification of solid waste generation volumes based upon actual field deployments. As stated in section 5.1, however, complete data was difficult to obtain, and when available, was more often than not unreliable. Therefore, information regarding municipal solid waste (MSW) generation in the United States was also used to derive estimates of the amount and nature of the non-hazardous solid wastes generated by a nominal 1100-person Bare Base deployment.

Operation Joint Endeavor camp data obtained representing weekly per capita solid waste generated by servicemen and BRSC personnel was analyzed. The weekly average for solid waste (in cubic meters) removed from each camp was normalized to the camp population to obtain the m^3/person/day for each camp. The average of 21 camps for which data was available was 3.2 ft^3/person/day (0.1 m^3/person/day), with individual camps ranging from 0.4 to 13.4 ft^3/person/day (0.01 to 0.4 m^3/person/day). Based upon 26.7 lb/ft^3 (427.6 kg/m^3) as the average density (U.S. EPA, 1995a), Operation Joint Endeavor personnel generated solid waste at an average rate of 84.9 lb/person/day (38.5 kg/person/day); the range was from 9.4 to 358.3 lb/person/day (4.3 to 162.5 kg/person/day).

The average solid waste generation rate by Operation Joint Endeavor stands in stark contrast to commonly accepted per capita rate for the United States as a whole. The U.S. Environmental Protection Agency periodically publishes an update of its *Characterization of Municipal Solid Waste in the United States* (U.S. EPA, 1995a). This document provides detailed information on the amount and nature of MSW generated in the United States in 1994, and compares this to trends in MSW generation since 1960, the first year for which comprehensive data is available.

U.S. EPA (1995a) reported a total of 209 million tons of MSW was generated in the United States in 1994, for an average generation rate of 4.4 lb/person/day (2.0 kg/ person/ day). Materials diverted for recycling, reclamation, etc., are normally not considered part of the MSW stream. Additionally, MSW does not, by definition, include (U.S. EPA, 1995b):

- any solid waste identified or listed as a hazardous waste;
- medical wastes;
- industrial solid wastes resulting from manufacturing processes;
- solid waste generated and disposed of on-site by the facility;
- materials or products returned to the manufacturer for credit, etc.

The per capita generation of solid waste was identical to that for 1993; the U.S. EPA expects a slow increase to 4.8 lb/person/day (2.2 kg/person/day) by 2010. The increase in per capita solid waste generation is largely due to increasing use of packaging (especially for food items); the recent leveling of increases in generation rate is believed to result from an increased diversion of yard wastes to composting.

The per capita generation of solid wastes produced by Operation Joint Endeavor was greater, by an order of magnitude, than that reported in U.S. EPA (1995a). Most likely, this resulted because many of the camps were still being constructed or expanded during the survey data collection. The solid waste generated by the camps thus contained far more construction and demolition (C&D) waste than would normally be expected. Such waste consists of scrap lumber and wood products (plywood, particle board, etc.), scrap plastic (PVC) pipe, bent or otherwise damaged fasteners (nails, screws), etc. Once construction was complete, it would be reasonable to expect the per capita solid waste generation rate to decline to a level much closer to that of the United States' population as a whole. Air Force publication AFPAM 10-219 *Guide for Bare Base Planning* reinforces this assumption by citing a solid waste generation rate of 4 lb/person/day (1.8 kg/person/day) for planning purposes.

Although the Brown & Root data from Operation Joint Endeavor specifies the volume of solid waste removed from camp, it gives no indication of the composition of this waste. Therefore, in order to estimate the composition of Bare Base solid waste by material type, municipal solid waste characterizations were reviewed. Table 5.3.1 presents the breakdown of 1994 MSW generations as cited in U.S. EPA (1995a).

Table 5.3.1.1. Municipal Solid Waste Generation in the United States in 1994

paper & paperboard	81.3 million tons	38.8% of total
yard trimmings	30.6	14.6
plastics	19.8	9.5
wood	14.6	7.0
food wastes	14.1	6.7
glass	13.3	6.4
ferrous metals	11.5	5.5
miscellaneous materials	6.7	3.2
textiles	6.6	3.2
rubber and leather	6.4	3.1
aluminum	3.1	1.5
other non-ferrous metals	1.2	0.6
TOTAL	209.1 million tons	

It is important to note that one significant component of MSW in the United States, yard trimmings (grass clippings, thatch, prunings, pulled weeds, etc.), would not normally be present in the waste stream of a temporary military installation (Bare Base). If grass or other ground

cover must be cut to satisfy aesthetic, security and/or safety concerns, it is be left where discharged by the mower, rather than collected for disposal. Normalizing the data after removing yard trimmings yields percentage factors one would more reasonably expect the Bare Base waste stream composition to resemble. Assuming a per capita generation rate of 4.4 lb/person/day (2.0 kg/person/day), the daily per capita generation of solid waste is estimated in Table 5.3.1.2.

Table 5.3.1.2. Estimated Bare Base Solid Waste Generation

paper & paperboard	45.5 % of total	2.00 lbs/person/day
plastics	11.0	0.48
wood	8.2	0.36
food wastes	7.9	0.35
glass	7.4	0.33
ferrous metals	6.4	0.28
miscellaneous materials	3.8	0.17
textiles	3.7	0.16
rubber and leather	3.5	0.15
aluminum	1.7	0.07
other non-ferrous metals	0.7	0.03
TOTAL		4.40 lbs/person/day

Note that except for yard wastes, neither categories nor related percentages were not adjusted. Given the potential proximity of civilians to the Bare Base and the variety of possible missions, Table 5.3.1.2 was considered representative of the Bare Base non-hazardous solid waste stream.

5.3.2 Hazardous Solid Waste

Although the United States per capita municipal solid waste volume was estimated to be fairly representative for Bare Base non-hazardous solid wastes, the U.S. EPA (1995a) MSW data does not specifically address household hazardous waste as a subcategory of solid waste. These wastes, called *universal wastes*, are not regulated under U.S. EPA Resource Conservation and Recovery Act (RCRA) regulations when generated by individual households; universal wastes generated by small and large businesses are regulated under RCRA, and these non-residential sources may be required to handle these materials as hazardous wastes.

The *Universal Waste Rule*, promulgated by U.S. EPA as an amendment to RCRA, was designed to reduce the amount of hazardous waste in the MSW stream, encourage recycling, and proper disposal of certain common hazardous wastes. While removing these materials from municipal landfills and incinerators prevents a potential threat to public health and the environment, the potential environmental, safety and health impact of any hazardous waste (HW) is significant for Bare Base waste processing. Universal wastes include materials such as: (1) batteries; (2) agricultural pesticides which were recalled, banned from use, obsolete, damaged, or no longer needed; and (3) thermostats, which can contain as much as 3 grams of liquid mercury.

Information about the quantities of household hazardous wastes (HHW) generated in the United States was difficult to obtain and essentially limited to a few studies which surveyed HHW generation in a metropolitan area. R.W. Beck conducted such a study for the EPA in Palm Beach County, Florida in 1993-1994, and the results of this study, published as *Household Hazardous Waste Characterization Study for Palm Beach County, Florida: A MITE Program Evaluation* in 1995. Because data concerning the amount of hazardous waste generated during Operation Joint Endeavor was not collected, U.S. EPA (1995c) formed the basis for estimating hazardous waste types expected to be produced during a Bare Base peacekeeping mission.

The U.S. EPA (1995c) study examined a large number of household waste samples obtained from both single and multiple-family residences to quantify the various types of hazardous waste disposed. Automobile related materials, paints, aerosols, cleansers and disinfectants, insecticides, batteries and adhesives comprised the largest groupings of HHW generated. The "other miscellaneous" subcategory consisted of 17 different HHW items, including materials such as ice packs, sealers, putty, glazing compound, nail polish and correction fluids.

Representative samples were screened for HHW items belonging to any of 39 subcategories, with the description and weight of each item logged. Estimates, by category, were made of the waste quantities disposed, or diverted to recycling or other uses annually. Disposed materials were defined as HHW disposed through the local government solid waste management facilities, while diverted HHW was those materials collected and either recycled by or disposed by the local government HHW collection facility. The authors estimated that approximately 0.1 % of total residential solid waste was hazardous in nature. Greater detail, along with the experimental procedures are discussed elsewhere (U.S. EPA, 1995c).

The U.S. EPA (1995c) categories were reviewed according to Bare Base activities, i.e flight line, industrial and housekeeping. The percentages of total reported for U.S. EPA (1995c), including the disposed and diverted HHW data, was reviewed to estimate Bare Base hazardous waste generation. Certain household specific hazardous wastes (HW) were eliminated, i.e. pool chemicals. Subcategories that the EPA study failed to detect any disposed or diverted quantities for were also reviewed for potential relevance to Bare Base activities. Adjusted HW categories were normalized to estimate the percentage of the daily generation of each HW type.

The hazardous waste content of the solid waste stream associated with Bare Base deployments are probably somewhat greater than 0.1% of the total MSW volume reported. Bare Base operations include activities generally regarded as industrial or commercial; potentially hazardous wastes generated would not have been captured in the U.S. EPA study. Although these wastes would be traditionally collected and recycled by contract services, materials such as used motor oil and other fluids, lead-acid batteries (automotive), solvents, thinner and paint would be considered hazardous if land filled. Additionally, the preventive maintenance required for the numbers and types of equipment associated with flight line operations, civil engineering or other Bare Base activities will result in a higher estimated per capita hazardous waste volume.

Table 5.3.2.1 lists the estimated hazardous waste generated, by category (U.S. EPA, 1995c), excluding *Acids*, *Bases*, and *Oxidizers*; these categories contributed 0.0% to the overall total. Numbers in parenthesis listed under the *Type of Hazardous Waste* column indicate the total subcategories identified in U.S. EPA (1995c).

Table 5.3.2.1. Estimated Daily Bare Base Hazardous Wastes Generation

Type of Hazardous Waste	% of Total, from U.S. EPA, 1995	% of Total, estimated for Bare Base	Pounds per day (estimated)
Automotive Related Materials (5)	**18.2**	**36.4**	**176.2**
Used Motor Oil	3.6	7.2	34.8
Oil Filters	11.7	17.8	86.2
Other Automotive Fluids	2.9	5.8	28.1
Antifreeze	0.0	2.8	13.6
Lubricants	N/A	2.8	13.6
Paints (2)	**4.0**	**4.0**	**19.4**
Latex - wet	3.1	2.0	9.7
Oil based - wet	0.9	2.0	9.7
Other Flammables (7)	**33.2**	**16.6**	**80.3**
Aerosols (not pesticides/Freon) *	31.3	14.6	70.7
Other fuels (natural gas, others)	1.5	0.8	3.9
Other explosives	0.4	0.2	1.0
Solvents (thinners, stains)	0.0	1.0	4.8
Non-Aerosol Cleaners (4)	**9.5**	**4.0**	**19.4**
Cleanser/disinfectant	8.0	3.4	16.5
Waxes/polishes (liquid)	1.5	0.6	7.3
Pesticides (4)	**14.8**	**4.0**	**19.4**
Insecticides	14.8	3.0	14.6
Rodenticides	0.0	1.0	4.8
Batteries (4)	**2.6**	**10.0**	**48.4**
Lead-acid	2.5	7.5	36.3
Lithium	0.1	1.0	4.9
Ni-Cd	0.0	1.0	4.8
Button	0.0	0.5	2.4
Miscellaneous (10)	**17.7**	**25.0**	**121.0**
Adhesives	9.3	13.1	63.4
Pool-chemicals	(0.4)	N/A	N/A
Other Miscellaneous	8.0	11.3	54.7
Asbestos	0.0	1.0	4.8
Freon	0.0	0.4	1.9
Fluorescent Tubes	0.0	0.4	1.9
Totals (36)	100.0	100.0	**484.0**

* No determination was made as to the percentage of flammable versus non-flammable aerosols
Total in parenthesis does not include categories *Acids, Bases* and *Oxidizers*

No more than two of these subcategories comprising the largest percentage of HHW generation from U.S. EPA (1995c) were listed. Any subcategory relevant to Bare Base activities was tabulated, regardless of percentage of total.

A per capita generation of HW equal to 10% of the Bare Base non-hazardous MSW daily volume was assumed. While a 10% factor is two orders of magnitude greater than the 0.1% estimated by U.S. EPA (1995c), this planning factor was considered appropriate when including disposed, diverted or recycled waste streams generated by flight line, industrial and housekeeping Bare Base activities. This is particularly significant for areas of operation or missions that preclude recycling of materials. Table 5.3.4 depicts the estimated daily pounds of HW generated by an 1100 person deployment, by primary grouping and subcategories, based upon a planning factor of 0.44 lb/capita/day.

For the primary U.S. EPA (1995c) categories, all groupings were determined relevant to flight line, industrial and housekeeping activities, except for *Automotive Related Materials*; it was noted, however, that *Automotive Related Material* subcategories were applicable to both flight line and industrial operations. Appliance lubricants were listed as a *Miscellaneous* subcategory in U.S. EPA (1995c), although automotive lubricants were not included under any grouping; these lubricants are major sources of Bare Base HW materials because of preventive maintenance. Bare Base antifreeze usage was also assumed to be potentially significant. Overall, *Automotive Related Materials* was increased by 100%.

While not considered a waste category for initial Bare Base construction, paints were assumed to potentially be used significantly during construction, especially in light of the construction materials generated during Operation Joint Endeavor. Additionally, *Other Flammable* subcategories, particularly *Other fuels* and *Other explosives* were considered relevant because of the diversity of equipment and potential combat or security activities; overall, *Other Flammables* were reduced by 50%. And although not listed in Table 5.3.2.1, the grouping *Pesticides* included fungicides and herbicides. While these materials may be required for sanitation or health challenges related to unique humanitarian missions, only insecticides and rodenticides were estimated applicable to the majority of Bare Base deployments.

Batteries will be discarded in much larger numbers at a Bare Base due to the attrition of starting batteries in vehicles and the need to maintain fresh, reliable batteries in field radios, night-vision goggles, and other portable electronic equipment. Because of the variety of personal and military equipment, coupled with the varying age of these items, a wide range of battery types was views appropriate. Note, however, that the estimated battery disposal volume can be better quantified by comparing the applicable Bare Base unit listings of equipment with planned preventive maintenance schedules. Battery volumes were increased approximately 400%.

Miscellaneous materials were considered potentially significant to Bare Base operations because of the heavy initial construction activities. Also, older portable air conditioning and refrigeration systems contain chlorinated refrigerants. Asbestos was included in the listing

because peacekeeping and humanitarian efforts in the Bare Base area of operations may require demolition or renovation of structures which already include hazardous construction materials. Finally, fluorescent light bulbs may contain mercury; although considered a universal waste, proper handling of fluorescent light bulbs was considered applicable.

It should be noted that the EPA Palm Beach County data does not address medical and biohazardous wastes, which could be of substantial importance in the Bare Base environment. Depending upon the mission and operational environment of the base, these wastes could range from a small quantity of used bandages and sharps (hypodermic needles, scalpel blades, etc.) to large quantities of bandages, surgical hardware, tubing, etc. all contaminated by contact with blood. A Bare Base supporting intensive combat operations may even be faced with the disposal of quantities of human body tissue, bone fragments, etc. It is impossible to estimate the nature and quantity of medical wastes generated unless certain particulars of the mission are defined.

5.4 Quantification of Bare Base Liquid Waste Streams

Estimated for liquid waste volumes and sources generated by a nominal 1100-person Bare Base deployment were based upon actual field deployments data and engineering factors (Metcalf and Eddy, 1991) derived for wastewater generation under typical usage categories. Because the field deployment data was incomplete and because the deployment may not be representative of the requirements for the most demanding scenario required of a Bare Base contingency, estimates were derived by examining overall category sources to adjust planning factors. The primary sources of wastewater generation were assumed to be domestic sewage (excluding showers and laundries), kitchen facilities, housekeeping (includes showers and laundries), and flight line or motor pool operations.

As detailed in section 5.3, data reflecting weekly average water delivery and liquid waste disposal was obtained from BRSC for seven separate Operation Joint Endeavor camps over a six week period during the spring season. Additionally, the existing and projected base population for each location was tracked. Initially, both the water delivered and liquid waste removed from each camp were compared, and then the per capita wastewater generation rate was calculated based upon the reported camp population.

These numbers were compared with similar values provided in Metcalf and Eddy (1991) as representative of typical wastewater flow rates. Derived from various sources that would portray sanitary wastewater (black water) generation only, the lowest value provided by Metcalf and Eddy (1991) for each source category was used for comparison with the BRSC water delivery value to estimate liquid waste generation. Table 5.4.1 depicts these results.

Several factors must be considered when evaluating the results listed in Table 5.4.1. First, depending upon location, some camps serviced by BRSC utilized a local Publicly Owned Treatment Works (POTW) for some, if not all of their potable water delivery and wastewater disposal. Water usage and liquid waste generation rates were therefore not calculated for these. In addition, this data was obtained during the spring season, so average or typical water

consumption rates may not accurately describe expected usage and thus disposal rates during warmer periods or in warmer locations.

Table 5.4.1. Comparison of BRSC Data with Established Wastewater Data

	Typical gals/person/day (liters/person/day)	Range gals/person/day (liters/person/day)
Water Delivery	14.8 (56.0)	7.1-19.0 (26.9-71.9)
Liquid Waste Disposal	2.9 (11.0)	1.4-5.3 (5.3-20.1)
Metcalf and Eddy (1991)		
Residential Sources		
trailer park	40 (151)	30-50 (114-189)
Commercial Sources		
industrial (sanitary)	13 (49)	7-16 (27-60)
Institutional Sources		
day school	11 (42)	5-17 (19-64)
Recreational Facilities		
day camp (no meals)	13 (49)	10-15 (38-57)

On average, the recovery rate of water delivered (liquid waste) was only 20% of the total delivered. Note, however, the per capita wastewater generation rate derived from the water delivery value appeared to most closely track typical wastewater generation values presented in Metcalf and Eddy (1991). Because Table 5.4.1 was developed to estimate sanitary wastewater (black water) generation, estimates for kitchen facilities, showers and laundries and flight line or motor pool operations (grey water) were derived in a similar manner for comparison with the limited BRSC data available. Table 5.4.2 depicts these results.

Table 5.4.2. Estimated Bare Base Grey Water Generation

	Typical gals/unit/day (liters/unit/day)	Range gals/unit/day (liters/unit/day)
Restaurant		
per meal	3 (11.4)	2 - 4 (7.6 - 15.1)
Cafeteria		
per customer	2 (7.6)	1 - 3 (3.8 - 11.4)
Laundry		
per machine	550 (2081.8)	450 - 650 (1703.3 - 2460.3)
per wash	50 (189.3)	45 - 55 (170.3 - 208.2)

The BRSC data revealed that an average of 1.19 prepared meals were consumed and 0.13 bags of laundry were generated per capita/day. Based upon Table 5.4.2, this would result in an additional 3 gallons/ person/day (11.4 liters/person/day) due to the kitchen operations and 6.5 gallons/person/day (24.6 liters/person/day) due to laundry operations. Wastewater generated from flight line or motor pool operations was considered negligible, aside from sanitary wastewater generation considered in other categories.

The assumed average liquid waste generation rate in Operation Joint Endeavor camps was 15 gallons/person/day (56.8 liters/person/day), with approximately 2.5 gallons/capita/day (9.5 liters/person/day) of black water liquid, 3.0 gallons/person/day (11.4 liters/person/day) concentrated solid wastes and approximately 9.5 gallons/capita/day (36.0 liters/person/day) of grey water. While this total approximates the typical value associated in the United States for dedicated, non-domestic sanitary wastewater generation rates, it is reasonable to assume the water delivery rate best approximates the water available for all source categories. Table 5.4.3 depicts the expected range of values determined in this analysis.

Table 5.4.3. Expected Bare Base Water Usage

	Typical gal/person/day (liters/person/day)	Range gal/person/day (liters/person/day)
Black water		
Liquid	2.5 (9.5)	3.0 - 6.0 (11.4 - 22.7)
Solids	3.0 (11.4)	2.5 - 5.3 (9.5 - 20.1)
Meals	2.5 (9.5)	2.0 - 3.0 (7.6 - 11.4)
Laundry	7.0 (26.5)	6.5 - 8.0 (24.6 - 30.3)
Total	15.0 (56.8)	14.0 - 22.3 (56.8 - 73.1)

The liquid waste removed may reflect an accurate estimate of concentrated, black water solids generated; this volume would include solids associated with water treatment or recycling of grey water. The meal production and laundry bag generation per capita also appear to be reasonable numbers which reflect the austere conditions of a Bare Base, so derived values are probably realistic. The balance of the water usage, assumed to be the liquid portion of the black water stream, is the value that is probably the most conservative, especially in warmer climates.

6.0 EVALUATION OF EXISTING BARE BASE WASTE SYSTEMS

While equipment, technology and strategies related to all aspects of Bare Base operations have evolved over the past 40 years, the incorporation of waste treatment as a core Bare Base function has not significantly occurred. As a result, the Bare Base not only does not include

equipment needed to process wastes, but current strategies to impact the magnitude of wastes generated may not be widely practiced. Because Bare Base waste processing has been reactive, current procedures do reflect use of new or emerging technologies. Therefore, evaluation of existing Bare Base waste systems requires an assessment of current and preferred practices in concert with equipment and technologies used to process wastes. This assessment, by default, includes operational guidelines, personnel and inter-related infrastructure.

6.1 Solid Waste Treatment

The present Harvest Falcon Bare Base kit contains only minimal provisions for the collection and processing of solid wastes. The existing disposal systems are not always adequate to satisfy health and environmental requirements. USAF Bare Base kits included an incinerator for disposal of solid wastes up until the early 1970s, when this piece of equipment was deleted from the table of equipment. The current Harvest Falcon configuration provides for disposal of solid wastes and hazardous wastes by land filling. Solid wastes are subjected to pre-treatment (sorting, recycling, volume reduction, shredding/compacting) and then land filled. Harvest Falcon kits do not currently incorporate any form of dedicated solid waste handling equipment. U.S. military Bare Base operations in the recent past have relied upon host nations to collect and dispose of solid wastes.

Landfill disposal requires the use of heavy equipment to prepare the landfill site, to collect and transport wastes to the landfill, and then to prepare and cover the wastes; future liability is also a potential major concern for the host nation. Sufficient overburden may not be available for covering land filled material on a daily basis to prevent an increase in insect and rodent populations.

Additionally, it is not always possible to construct a landfill where desired, for a number of reasons. The geophysical characteristics of a proposed landfill site may encourage unacceptable leaching by groundwater; this could be the case in areas incorporating springs, sand dunes, mine shafts, and other features which provide for ready transport of groundwater-borne leachates. Locating a landfill at a distance from the Bare Base sufficient to minimize the health threat posed by such vermin may be impossible, given terrain, political, and mission constraints. Finally, degraded living conditions and troop morale may result from real or perceived issues.

6.2 Wastewater Treatment

Unlike solid waste, liquid wastes are generated primarily as a result of sanitation and hygiene activities of personnel in a Bare Base operation. Wastewater sources include concentrated "black water" such as latrine wastes, and more dilute "grey water" from laundry, shower, kitchen, and other functions. Equipment wash down, vehicle and aircraft maintenance, and other operational activities also produce primarily "grey water," although this liquid waste may contain hazardous chemicals or materials which should not be discarded to the environment.

The present Harvest Falcon kit relies upon the construction of stabilization ponds for wastewater treatment during austere, baseline deployments. While considerations such as site

configuration and soil permeability, wastewater treatment required, time to construct, and operational environmental health issues (insect breeding, odor, etc.) must be evaluated, stabilization ponds afford a simple, low cost method for containing nonhazardous wastewater.

As an alternative, recent Bare Base operations have elected to discharge all wastewater generated to local Publicly Owned Treatment Works (POTWs) wherever possible or use contract services for water/ wastewater procurement and disposal. Portable toilets or excavated latrines have also been used. In these cases, wastewater generated in kitchens, shower and laundry operations is discharged to either collection basins or to septic tanks. While excavated latrines and septic tanks are viable, well-tested solutions, especially in austere locations, both can require more extensive engineering, materials and multiple-site locations. Additionally, excavated latrines and septic tanks can produce groundwater pollution or function poorly in porous or non-permeable soils, respectively.

Selection of appropriate wastewater treatment systems is based upon the quality and quantity of wastewater produced. Bare Base operations, as evidenced by Operation Joint Endeavor, primarily generate domestic wastewater, and this liquid waste is amenable to treatment described above. However, Bare Base operations may potentially, over the course of the life of the deployment, generate waste streams that resemble those found in domestic, industrial, medical activities, or a combination of the above. As a result, the wastewater treatment system planned for a multi-contingency force, operating in various environmental conditions, must be robust or designed to treat only selected waste streams.

The minimal primary wastewater treatment method generally provides adequate area and volume for settling solid materials from the liquid waste stream, with the liquid discharged to a receiving stream or to a local POTW for further treatment. In isolated areas where odor and insect breeding are not sanitation or health considerations that affect operational activities, or for waste streams that are not heavily polluted (grey water, or settled black water), evaporation can be used to remove excess water.

Secondary treatment, or biological conversion of organic matter contained in wastewater, follows primary treatment if the wastewater discharge standards require further treatment. Secondary treatment requires more advanced engineering and control, along with additional power and equipment. The most complete treatment is tertiary treatment, with filtration following biological treatment to remove bacteria and other small particles. For all levels of treatment, solid residuals are produced that must be eventually concentrated and stabilized before disposal.

6.3 Evaluation of Operational Effectiveness, Maintainability, and Reliability

Although a rigorous evaluation of the operational effectiveness, maintainability, and reliability of existing Bare Base waste disposal systems is best accomplished by examining the most recent MOOTW deployments, such an evaluation would be biased because the waste processing systems used were developed on a reactive versus proactive basis. This is also true of

the Desert Storm experience; once the war began, waste processing was conducted only as needed to address sanitary concerns.

Operation Joint Endeavor, the MOOTW reviewed for this study, provides a representative example of how Bare Base waste disposal systems are operated. Solid and liquid waste streams have most often been delegated to local contractors, and this will continue to be the most economic and operationally effective method for processing waste during deployments to low threat areas. Waste disposal via local vendors can enhance relationships with local communities, facilitate waste recycling and reuse, and take advantage of local infrastructures. Disadvantages to using local vendors include reliability, security issues, and operational vulnerability if these services are abruptly discontinued with no contingency plans in place. Additionally, if contractor disposal methods are not verified, the potential impact of future liability could exist. For Operation Joint Endeavor, contractor disposal methods were not reported.

The waste generation rates derived from the BRSC data highlighted these issues. Data was available to build a framework for determining the volume of liquid and solid wastes produced during actual Bare Base operations, but the data provided was incomplete and sporadic. Additionally, without knowing how waste streams are ultimately disposed, waste disposal may simply result in off-base pollution as wastes are transferred to local areas not designed for disposal. These situations could result in a potential long-term liability issue. Furthermore, ensuring wastes are ultimately treated or disposed in a manner that complies with the environmental policies of the United States, the Air Force, and of the host nation must be considered, especially under low to no threat scenarios.

Solid and liquid wastes can be treated or disposed on-site or off-site. Treatment can be as simple as storing the material or can include handling, storage, treatment and disposal. Disposal generally is defined as discarded, abandoned, recycled, reclaimed, burned or used in a manner constituting disposal. Currently, recycling/reuse, burial, and incineration are the predominant methods for disposing of solid wastes, both on- and off-site. While energy recovery may be the primary reason for burning materials, for this study energy recovery is noted as a potential use only for off-site purposes.

Liquid wastes generally require more intense handling, storage and treatment phases before disposal as compared to solid wastes, simply because solid waste is more amenable to storage before treatment or disposal. While recycling/reuse are viable means for liquid waste treatment, current operations generally rely upon local Waste Water Treatment Plants (WWTP) or lagoons for treatment and/or disposal.

Table 6.3.1 highlights considerations of currently used practices. Note that for solid waste, on-site storage and/or treatment is the most reliable with regard to maintainability and reliability. Land availability is the limiting factor, especially considering large quantities of construction wastes which can be generated, as demonstrated by Operation Joint Endeavor. On-site solid waste treatment, however, will greatly diminish operational effectiveness, will be manpower

intensive, and could potentially cause sanitary concerns based upon the nature of the solid waste. It should be noted that recycling/reuse can reduce airlift requirements if material usage is planned in advance to minimize wastage, and because these impacts are a result of individual efforts, small savings by each engineer will have a tremendous overall effect. Also, burial and incineration have potential liability aspects and are not in keeping with the highest tenets of current environmental treatment priorities.

Table 6.3.1. Operational Effectiveness, Maintainability, and Reliability of Current Practices

	Operational Effectiveness	Maintainability	Reliability
Solid Waste Treatment - On Site			
Recycling/Reuse	minimized airlift requirements	manpower intensive combat limitation	waste pre-sorting dependent
Burial	potential long-term liability	heavy equipment intensive	impacted by space available
Incineration	some air pollution unavoidable	equipment dependent	high
Solid Waste Treatment - Off Site			
Recycling/Reuse	possible to enhance community relations	potentially unreliable	potentially unreliable
Burial	potential long-term liability	heavy equipment intensive	high
Incineration	air pollution possible ash disposal	equipment is simple	operational security
Liquid Waste Treatment - On Site			
Containment	potentially diminished	limited in capacity	sanitary issues
Excavated Latrines	high	minimal attention required	sanitary issues
Liquid Waste Treatment - Off Site			
Local WWTP	high	complex system, but maintained by operator	high
Portable Toilets	potentially diminished due to capacity constraints	easily maintained, but manpower intensive	high

Liquid waste treatment on-site is influenced more by climatic extremes than that of solid waste, because both cold and hot weather can impact storage and treatment. Although liquid

wastewater treatment at local treatment facilities, along with use of portable toilets that are emptied by vendors, is most advantageous to the Bare Base deployment, these practices greatly reduce operational effectiveness if disrupted. Current on-site practices, i.e. lagoon and excavated latrine containment, can also disrupt operational effectiveness if sanitation is not monitored.

The Bare Base solid waste processing system should provide: (1) hazardous waste treatment and/or storage during low to no threat scenarios to minimize liability and environmental impacts; (2) capability to treat and/or dispose of municipal solid waste that can potentially impact sanitation, and thus operational effectiveness; and (c) the ability to stabilize NBC related wastes if needed. If possible, the Bare Base liquid waste processing system should be designed to use recycling/reuse to ensure that sanitation issues do not impact operational effectiveness.

7.0 EVALUATION OF POTENTIAL WASTE TREATMENT TECHNOLOGIES

The evaluation of potential waste treatment technologies is a crucial aspect of the current operational guidelines and procedures for handling and processing existing waste streams. This study has detailed the current Bare Base practice of using local vendors wherever possible, but is has also highlighted the potential impact outsourcing may have under contingencies that require higher levels of on-site security or pose immediate threats to base personnel or force security.

Potential waste treatment technologies were examined for flexibility, applicability to the diverse waste streams potentially encountered during various Bare Base contingencies, system benefits and requirements, and future environmental regulatory impacts.

7.1 Solid Waste Treatment Technologies

Regardless of the technology or technologies employed to treat and dispose of the solid waste generated by Bare Base operations, the waste must first be collected, handled and stored or pre-processed. Functional considerations include sorting/separation, transfer, logistics, storage.

7.1.1 Background

Material pre-processing before solid waste treatment is critical to Bare Base operational aspects primarily because of health and sanitation. Sorting/separation, recycling or recovery greatly reduce volume, thus impacting storage and treatment; these activities are also manpower intensive. If neglected due to operational constraints, or if all material is simply shredded or compacted to reduce volume, health concerns remain, especially if putresible materials are resident in the solid waste. As noted in section 5.3.2, failing to remove hazardous waste components from the waste stream can also have implications ranging from compliance with local regulations or internal environmental management systems, to future liability.

Operational guidelines should stress reducing and pre-sorting of solid waste streams by the individual before discarding any waste to ensure putresible, recoverable and/or hazardous materials are properly collected and stored away from materials to be treated. These actions will

minimize, control or eliminate the health, sanitation or environmental impacts that may occur during periods of operational activity.

7.1.2 Land filling

A major attraction of land filling is that it is generally not operationally limiting; most Bare Base solid wastes can be land filled without extensive pre-processing. Because of this relative insensitivity to the feed waste stream, land filling does not necessarily require labor-intensive pre-treatment (sorting). In addition, land filling is relatively simple and inexpensive. However, materials characterized as hazardous under United States regulations should not be land filled in host nations, so these items would require separate handling, storage and disposal.

The greatest limitation of land filling, if practiced according to current United States regulations, would be the expense of lining and monitoring the site. These provisions are designed to minimize or prevent contaminants from leaching through to the groundwater.

7.1.3 Composting

Composting is essentially the microbial conversion of biodegradable organic wastes into a relatively stable humus. The conversion is carried out by thermophilic bacteria which utilize the organic waste as a substrate. From the standpoint of waste management, composting can be viewed as a relatively inexpensive method of achieving reductions in the volume and mass of solid waste.

The rate at which biological activity, and therefore waste decomposition, proceeds in a composting system is governed primarily by microbial population(s), moisture content, oxygen availability (aeration), nutrient balance (carbon availability), pH, and temperature. Although the composting process is robust in that it does not require exacting control of these parameters, maintaining the process within a certain operational window will ensure degradation of target contaminants and the production of a stabilized end product. Variation in the composting feedstock may require adjustment of certain operational parameters, particularly aeration rates, temperature, and retention and curing times.

Composting techniques are generally classified as either confined or unconfined. Unconfined processes include windrows and aerated static piles; aerated static piles include individual piles and extended piles. For successful composting, each process requires raw material which is porous, structurally stable, and contains sufficient degradable material to autogenerate heat from the oxidation of volatile matter, thus raising the reaction temperature.

Windrow systems rely on natural ventilation with frequent mechanical mixing to maintain aerobic conditions. Although simple in concept, the efficiency of such systems is limited because of oxygen limitations; additionally, mechanical mixing to aerate the pile is not an exact procedure and excessive mixing can over-aerate the pile and result in cooling. Because of large, exposed surfaces and the insulation capacity of the windrow, temperature profiles throughout the windrow can vary greatly from the center to exposed edges, resulting in inefficient treatment.

Aerated piles were developed to reduce land requirements and other problems such as odors associated with windrows. Aerated piles utilize forced-aeration to more uniformly aerate compost material, thus keeping temperatures lower and enhancing drying. Temperature feedback systems can assist in controlling aeration and minimize inefficiencies of mechanical mixing alone. Retention times of aerated piles tend to be shorter and odors generated from anaerobic pockets are also minimized. Extended aerated piles are simply series of individual piles built daily; aeration piping is added to interface the old pile and new material added.

Confined composting systems are typified by numerous proprietary systems. Such systems employ mechanical mixing at a set sequence and may also include aeration. Some provide tumbling, dropping material from one floor to the next or an endless belt with forced bottom aeration and stirring. The brief detention times usually require additional maturation in static piles. Confined systems typify the current composting technology for municipal solid waste.

The ultimate effectiveness of composting as a method for treating solid waste is proportional to the degree to which the waste material is biodegradable. Little mass and volume reduction will be achieved in a system in which the feedstock is of low biodegradability. An additional concern when composting mixed solid wastes is the presence of compounds or agents toxic to the micro flora driving the composting process. A solid waste stream containing small, concentrated amounts of hazardous materials can effectively limit short-term treatability.

7.1.4 Incineration

Incineration is a thermal process which employs combustion to oxidize refuse. Incinerators can be grouped by the type of feed stock, either as-received or sorted refuse. As-received systems process waste in a mass burn configuration and are the most common type of MSW incinerator in use today. Sorted refuse incinerators process only waste materials which have been determined to assist in the combustion process, normally by providing some fuel value. Both types of incinerators can be configured to recover waste heat for generate steam.

A broad range of gaseous products result from combustion of solid waste, including water vapor, CO_2, HCl, SO_2, No_x, vaporous forms of metals and organic species, and solid particulate matter. The gaseous products escape to the atmosphere; a portion of the solid particulate matter remains as ash (fly ash and bottom ash).

Release of air pollutants is limited by an air pollution control (APC) system. APC systems are generally comprised of dry, semi-dry, and/or wet scrubber systems with particle removal by baghouses or electrostatic precipitators. Dry and semi-dry scrubbers treat combustion gases by chemical conditioning and cooling techniques (water spray and acid gas neutralization). Wet scrubbers remove gaseous contaminants by spraying a fine mist of acid through the exhaust gases, thereby providing nuclei to promote condensation of gases.

Incinerators are effective in mass reduction of all types of solid waste, including bio-hazardous materials. Incineration can typically achieve an 80% reduction in volume and 50 to

60% reduction in mass. Utilization of waste heat from combustion to provide steam is a mature and easily implemented technology.

The ash generated as an end product contains ferrous and non-ferrous metals which can leach out if the ash is land filled. Incinerator ash is therefore subject to RCRA monitoring for leaching if land filled. In addition, the numerous gaseous by-products of combustion mandate the use of an air pollution control system.

7.1.5 Plasma Torch

Plasma is often referred to as the "fourth state of matter," since all atoms break down into a mixture of nuclei and free electrons at sufficiently high temperatures (10^4K and above). Effectively an ionized gas, plasma occurs naturally in the form of lightning and is can be readily produced by a plasma torch. Developed over 30 years ago by the National Aeronautics and Space Administration (NASA) to simulate the effect of re-entry temperatures on heat shields for manned spacecraft, plasma technology has commercially emerged in a number of industries.

The plasma torch system converts electrical energy into thermal energy to create the plasma arc. Plasma acts as a resistive heating element and maintains a temperature around 21,600^{0}F (12,000^{0}C); this provides a distinct advantage over solid heating elements because it will not melt and thus fail. The plasma arc creates a "flame" that has temperatures ranging from 7200^{0}F to 12,600^{0}F (4,000^{0}C to 7,000^{0}C), hotter than the surface of the sun.

The plasma torch system consists of the following components: the plasma arc torch assembly, power supply and control panel, closed-loop water-cooling system and heat exchanger, and a gas source. Off-gas treatment is also required for many applications. A plasma torch system can, however, be readily transported. Several plasma arc torch *ex-situ* furnace processes have been developed for the destruction of a variety of waste materials, and these systems have been successfully tested.

Plasma torches operate at much higher temperatures, higher enthalpy, and greater efficiencies than those of fossil-fuel burners. Because plasma torches require only about 5 percent of the gas necessary for fossil fuel burners, waste effluent gases are also greatly reduced. As a result, plasma furnace systems are more compact than traditional furnaces and have reduced capital costs.

The very high temperatures and energy densities, in conjunction with the ionized and reactive medium, have fully demonstrated the potential of plasma arc technology to eliminate many waste materials in an environmentally safe and cost-effective manner.

The Ontario Ministry of Energy (1992) concluded plasma gasification was an efficient municipal solid waste disposal technology with significant environmental improvements over existing incineration technologies, particularly in the areas of gaseous emissions and leachate toxicity. Additionally, Circeo *et al.* (1997) estimated the heating value of the off gases derived

from processing land fill wastes was over four times the plasma heat input required for processing; cogeneration or the production of alternate fuels were theorized. The process by-products is a vitrified, rock-like material similar to obsidian; this vitrified material is durable, strong, and highly resistant to leaching, with materials readily pass all standard leaching tests.

Plasma arc torch technology is currently being used or planned for a variety of industrial and experimental *ex-situ* applications. Some of these processes listed in Table 7.1.5.1 have been commercialized, while others are still in the development stages.

Table 7.1.5.1. Plasma Arc Applications

Titanium scrap melting	Shale oil recovery	Iron ore reduction	Waste treatment
MgO refractory production	Platinum recovery	Glass melting	Zinc recovery
Silicon metal production	Chemical synthesis	Ferro-alloy production	Molten steel ladle heater
Equipment volume reduction	Coal gasification	Treat Incinerator ash	Powdered metal production

Ex situ and *in situ* applications of plasma arc technologies have been investigated for hazardous and nonhazardous waste streams. For *ex situ* use, Resorption Canada Limited (RCL) reported a prototype 150kW plasma torch processed 500 pounds of MSW per hour (Carter, 1988). *In-situ* (borehole) thermal vitrification by plasma torch has been recognized as a method for remediation of buried wastes, and an *in situ* process has been patented for "remediating" MSW landfills (Circeo *et al.*, 1993).

7.1.6 Conclusions

Solid waste residuals must be collected, packaged and disposed. While residuals may be stabilized, i.e. further significant decomposition of any remaining organic materials is unlikely, the residuals must still be disposed. Processes that yield a usable end-product which can be handled, transferred, stored or used without special precautions benefit the Bare Base operations.

Plasma arc technology appears to be a viable technology for Bare Base solid waste treatment and disposal. Demonstrated processing of non-hazardous and hazardous wastes to date, along with its ability to produce a useable end-product, warrants further investigation.

7.2 Wastewater Treatment Technologies

Wastewater processes necessitate addressing handling of liquid and residuals, storage, treatment and disposal. While many wastewater treatment technologies are applicable to the liquid waste stream generated by Bare Base operations, the dynamic nature of the operational guidelines suggests that any technologies selected should require minimal operator attention in addition to meeting the priorities previously developed for Bare Base equipment. This section discusses potential treatment technologies and strategies.

7.2.1 Background

The level of treatment required to discharge wastewater to the environment varies throughout the United States, depending upon the location of the discharging facility. Assuming

these standards will vary by even a larger margin throughout the operational theaters where Bare Base contingencies may be deployed, selecting an appropriate technology becomes more difficult. Selection is even further complicated by the varying operational missions and environmental factors associated with geographic location. Currently, Bare Base operations prefer discharging all wastewater generated to local Publicly Owned Treatment Works (POTWs). Portable toilets or excavated latrines are also used, but wastewater generated in kitchen, shower and laundry operations is discharged to collection basins such as lagoons.

7.2.2 Relevant Technologies

Lagoons are low lying or excavated areas engineered to capture and store wastewater; they are best suited when a natural terrain depression exists and the underlying soil is not permeable, i.e. clay. These systems are simple, quick to emplace, low cost and require only sufficient elevation change or pumping to move wastewater from the Bare Base. Because these systems are designed more for liquid storage and removal of solid materials versus biological or secondary treatment, however, organic matter conversion rates are minimal. This low rate of wastewater treatment thus requires a larger volume to increase the overall treatment time afforded. Lagoons should also be lined to minimize the impact upon the surrounding area. Additionally, disease vectors such as mosquitos and other sanitary hazards may result if the organic loading to the system is excessive. These systems work best when the wastewater contains minimal pollutants.

Aeration increases the treatment rate provided by lagoons. Aeration stimulates the growth of the endogenous microbial population required to treat the wastewater, keeps the lagoon mixed, and prevents the onset of anaerobic or septic conditions and resulting odor. Aeration also increases the sludge generation rate and requires power for aerators. Additionally, primary treatment such as screening of raw wastewater becomes more important when focusing upon enhancing biological treatment of wastewater.

Packaged systems are available for treatment of small quantities of wastewater. These systems are generally used by small communities or towns because all relevant unit processes are contained in one unit, and the package provides a high rate of wastewater treatment. While these systems can be complex, costly and operator intensive, the package contains screening, primary treatment and secondary treatment equipment needed to process wastewater for discharge.

While operational scenarios and guidelines directly impact waste treatment processes, strategies which ensure processed wastewater contain minimal contaminants enhances treatment, reduces overall complexity and costs. These activities also improve sanitary conditions.

7.2.3 Supercritical Water Oxidation

Supercritical, water oxidation (SCWO) is an emerging technology under development by numerous laboratories and industries as a method for treating hazardous aqueous wastes. The process relies upon the solvating properties of water in its supercritical condition to destroy organics. As water is heated beyond its critical temperature (374.1^{0}C) and critical pressure (250 Mpa-s, or approximately 3219 psi), the density of the water drops to about a tenth the density of

liquid water and exhibits physical characteristics of both liquids and gases. While inorganic substances become nearly insoluble, organics become highly soluble; due to the high process temperature the oxygen rich environment, a wide variety of organics is efficiently destroyed (destruction and removal efficiencies better than 99.99%) in residence times of less than a minute. The process is considered applicable to waste streams containing 0-20 percent organics in water, although commercial processes are also being investigated that treat non-hazardous solid and domestic liquid waste streams.

SCWO processes typically combine boiler high-pressure steam (250 psi) heating with a feed waste stream provided by a high-pressure pump in the operating reactor; vaporized liquid oxygen is also used to enhance oxidization. Under operating conditions, many organic materials are miscible in all proportions, as are the combustion gases such as O_2, CO_2, and N_2. As a result, oxidation reactions proceed in a single phase without the delays associated with interphase transport. Organic carbon is transformed to carbon dioxide, and organic nitrogen and inorganic nitrogen are converted into nitrogen gas (also, liquid soluble nitrates, but no No_x). Organic halogens are converted to H-X substances, with organic and inorganic sulfur transformed into sulfuric acid (no SO_x generation). Additionally, volatile solids are destroyed, heavy metals are oxidized to the highest oxidized state, and inerts separate as fine, non-leachable ash.

Current SCWO designs can provide complete destruction of a fairly concentrated organic waste stream. Energy recovery (steam) is also possible with heat exchangers. SCWO processes can be used on-site and are designed to provide alternative treatment technologies to incinerators, boilers, industrial furnaces and kilns. The SCWO technology has been commercially recommended as a treatment method for chemical industry processes, papermill operations, refineries and municipal POTWs sludges, in addition to concentrated organics such as residual hazardous materials generated by military facilities.

7.2.4 Treatment Strategies

Section 5.4 described the major projected sources and quantities of wastewater generated by an 1100 person Bare Base deployment force. Blackwater or domestic wastewater, kitchen operations and showers/laundries were estimated to be the primary contributors to any treatment technology selected. While combining these waste streams is applicable for treatment in a lagoon, treating these waste streams separately is the most feasible solution for a Bare Base contingency. This can prevent dilution of treated wastewaters and thus minimize the size, complexity and cost of treatment technologies.

7.2.4.1 Waste Stream Segregation

Because domestic or black water is comprised of liquid and solid (organic and inorganic) waste, separating liquids from solids reduces the overall organic loading in the liquid steam. Commercially available portable toilets or composting toilets are options. Portable toilets designed to separate liquid and solid wastes allow treatment of the liquid portion in septic tanks while the solid material can be collected for composting, or incineration, or vitrification. Although the entire blackwater stream could be treated in septic tanks, portable toilets which

separate liquid and solid wastes provide dispersed facilities, and smaller septic tanks with longer lives are possible due to the reduced organic loadings.

7.2.4.2 Composting Toilets

Composting toilets, also known as dry, waterless or biological toilets, were introduced in the mid-1970s. Traditional markets for these systems have been public parks, highway rest stops or locales where municipal sewer systems are unavailable or inappropriate. Composting toilets have not found wide-spread application in residential settings because of local plumbing codes and because regulators tend to view such systems as experimental when municipal sewer hook-ups are available. In areas where composting toilets have been allowed in new construction, flush toilets were also required (Riggle, 1996).

Several states, however, are beginning to consider composting toilets as an environmentally beneficial alternative to septic tanks. Additionally, these systems can be viable alternatives as cost-effective upgrades for failing systems at difficult-to-reach locations. Internationally, composting toilets are being used in developing nations as a low-cost, environmentally friendly alternative to septic tanks or direct discharge to surface waters.

7.2.4.3 Grey water Reuse

Shower and laundry wastewater (grey water) generally contain low organic loadings, therefore these wastewaters are more amenable to recovery. Several commercially available systems exist to accomplish this; these systems include dual-recovery piping and storage capacity. While reusing grey water reduces the wastewater volume requiring treatment, a sludge residual would be generated. This residual material could be concentrated via evaporation, used as a composting process amendment, vitrified, or disposed of as solid waste.

7.2.4.4 Source Reduction

Eliminating the organic loadings to wastewater greatly reduces the treatment requirements. While reducing organic loadings to grey and black water is not possible other than separating the liquid and solid components and then concentrating the solids, minimizing the organics introduced into kitchen wastewater is easily accomplished. Source reduction practices that minimize the initial rinsing or washing conducted before gross solids are collected in receptacles can greatly reduce organics in kitchen wastewater.

7.2.5 Environmental Regulatory and Management Considerations

Department of Defense activities now evaluate environmental impacts associated with all actions as a result of the National Environmental Policy Act (NEPA) and the Federal Facilities Compliance Act (Freeman, 1997; McGhin, 1997). For acquisition and existing systems, environmental factors and compliance must be addressed; hazardous material use and/or storage, air, water or land resource impact(s), and biological or cultural consequences are major considerations for conformance (McGhin, 1997). Voluntary environmental performance, however, is also becoming increasingly the standard for large organizations.

ISO 14001 is one such environmental management system (EMS) that has become widely accepted as a measure of performance because it does not standardize requirements, but instead calls for specific commitments. These include commitments to: (1) establishing procedures to evaluate compliance with relevant laws; (2) continual EMS improvement; and (3) a philosophy of pollution prevention wherever technically and economically possible (Casio, 1997).

7.2.6 Conclusions

Selection of appropriate wastewater treatment technologies for Bare Base deployments can be greatly impacted by ensuring (1) waste stream segregation and separation, (2) grey water reuse, and (3) source reduction strategies are employed. If used, septic tanks systems for the liquid portion of blackwater, reuse and recycle of housekeeping grey water (shower and laundry), and composting, or incineration or vitrification of solids residuals concentrated from wastewater appear to be the most appropriate technologies.

Table 7.2.5.1 depicts the applicability of the waste treatment technologies to the expected Bare Base waste streams. While no ranking is made, one should note the applicability of each technology to the Bare Base waste streams generated. Also, compliance with U.S. EPA, Air Force or host nation regulations is inherent to selecting an applicable technology.

Table 7.2.5.1. Applicability of Waste Treatment Technologies to Bare Base Waste Streams

	Solid Waste Non-hazardous (MSW)	Solid Waste Hazardous	Medical or Biohazardous	Liquid Wastes (Liquid portion)	Liquid Wastes (Solids portion)
Land filling	Yes	Only if designated	Only if designated	No	If properly pre-treated
Composting	Yes	Possible	Improbable	Limited amounts Generally, no	Yes
Incineration	Yes	Yes, if designed	Yes	No	Possible
Plasma Torch	Yes	Yes	Yes	No, but possible[1]	Yes
Lagoon	No	No	No	Yes	No
Aerated lagoon	No	No	No	Yes	No
Package Systems	No	No	No	Yes	Yes
Treatment Strategies					
Source Reduction	Yes	Yes	N/A	Yes	Yes
Stream Segregation	Yes	Yes	Yes	Yes	Yes
Composting Toilets	N/A	N/A	N/A	Yes	Yes
Grey water Reuse	N/A	N/A	N/A	Yes	N/A

Note 1 - the high energy requirements make this an extremely inefficient process

8.0 DEPLOYMENT CONTINGENCIES

While a broad range of deployment contingencies can be envisioned for Bare Base deployments, combat flight, peacekeeping, and humanitarian represent a reasonable continuum with regard to combat and MOOTW actions. These contingencies could occur on any continent, thus operations may be conducted under a wide spectrum of environmental conditions.

The impact of trends affecting future Bare Base waste systems (section 3.1) were assessed to quantify and qualify existing Bare Base waste systems deployment contingencies based upon mission scenarios and operational environments in the context of this study. These trends are briefly summarized as: (1) Bare Base operational missions are expanding and impacting waste systems and strategies; (2) utilities and facilities technologies and requirements change, waste streams evolve, necessitating the investigation and proving-out waste treatment technologies, along with operational changes to reduce, reuse and recycle wastes at the source; and (3) relevant environmental policies regarding environmental stewardship are incorporated into all facets of its operations, meeting or exceeding environmental mandates will continue to impact Bare Base utilities and facilities decisions.

8.1 Mission Criteria

The type of mission supported impacts the Bare Base waste processing, and all other subsystems, because different missions will generate different types and quantities of wastes. The Harvest Falcon kit was nominally intended to support a squadron of tactical aircraft operating from a forward location for a relatively short period of time; the tenant squadron could be anything from F-16C Fighting Falcon fighters performing the CAP (combat air patrol) mission over uncontested airspace, to a handful of AC-130H Spectre gunships providing covering fire for engaged ground forces. In the case of the F-16s on CAP, Bare Base waste generation includes more used engine oil, contaminated hydraulic fluid and lubricants, and contaminated solvents than usual, simply due to the increased maintenance activity resulting from the high number of hours flown. The AC-130 gunships, in addition to flying long missions and generating liquid wastes similar to the F-16s, also consume large quantities of ammunition and thereby generate large quantities of discarded minigun and cannon ammunition containers.

In the post-Cold War era, the overwhelming majority of USAF deployments to unimproved facilities have supported MOOTWs and not strictly combat aircraft operations. A Bare Base deployment might be undertaken to support United Nations peacekeeping efforts; recent events in Africa suggest that the primary mission of such a base could rapidly shift from supporting peacekeeping to providing relief for refugees from contested territory. In such an event, a Bare Base waste processing system could be severely strained by the massive increase in both wastewater and solid wastes resulting from the influx of people. Combat operations resulting in aircrew casualties or relief operations treating sick and/or injured refugees generate substantial quantities of biohazardous wastes. As mentioned in section 5.3, such wastes represent a dire health threat unless properly handled.

Because the nature and quantity of waste generated can vary radically depending upon the mission, it is imperative that any future Bare Base waste treatment system(s) be designed to accommodate the full range of conditions anticipated. Also, as noted by Sverdrup (1996), mission requirements may necessitate specific packages for unique contingencies.

8.2 Operational Environment

The operational environment, perhaps even more than mission type, may effect Bare Base waste processing system(s). While the climatological conditions will directly impact waste processing, threats from small unit special forces or irregulars may impact Bare Base survivability, requiring a combination of dispersal, redundancy, and security or hardening.

Many wastewater treatment processes, including anaerobic and aerobic lagoons, are temperature dependent because treatment relies upon the biological activity of micro flora to remove organic contaminants from water. The metabolic rate of such organisms declines rapidly with decreasing temperature. As a result, an aerobic lagoon which is optimally sized to handle a given waste stream at a Bare Base in sub-Saharan Africa may be utterly useless in the markedly cooler climate of northern Asia. Also, while biological treatment improves with increase ambient temperature, warmer climates may reduce aesthetic considerations, i.e. increased odors, or sanitation or health issues such as vector control (rodents, mosquitoes, etc.).

Sverdrup (1996) also highlighted unique Gulf War issues that, if analyzed improperly, may impact Bare Base assumptions and/or lessons learned. These included: (1) medical waste quantities were insignificant and relatively easy to handle due to low casualties; (2) lax environmental demands allowed hazardous wastes and contaminated petroleum products to be disposed of in land fills or with other non-environmentally stable methods; additionally, non-hazardous solid wastes were stored in 55 gallon drums, and still present a disposal challenge in the region due to the potential of hazardous wastes; and (3) the arid environment minimized the health effects of poor sanitation and waste disposal, which will be potentially disastrous in humid tropical regions.

8.3 Comparative Assessment of Treatment Technologies

All Bare Base activities, utilities and facilities will be impacted by the mission associated with the Bare Base deployment contingency and the operational environment. The importance of these factors, relative to waste processing, will also depend upon the deployment duration, the austerity of the location, and the number of humans in the immediate Bare Base area of operation. The mission, operational environment and other related factors have produced the recent Bare Base waste processing practice of using contract vendors or local POTWs, and future scenarios may create significant variations in sources, types and volumes of wastes generated.

8.3.1 Qualification of existing Bare Base Waste Systems Deployment Contingencies

As previously stated, the trends affecting future Bare Base deployments serve as the basis of comparing applicable treatment technologies. While the potential impact of expanding Bare Base operational missions and the evolving waste stream characterization associated with newer

technologies and strategies are challenges the Bare Base has directly or indirectly met in the past, the impact of relevant environmental policies regarding environmental stewardship is a new facet that must be considered when analyzing applicable Bare Base waste processing approaches.

To address the importance of environmental stewardship within the Bare Base waste processing subsystem, candidate treatment technologies were evaluated against:

(1) U.S. EPA hierarchy for waste disposal, along with tactical considerations;
(2) categorization of wastes to determine the impact of process location, i.e. centralized for isolated operation, and energy requirements for collection/disposal;
(3) multiple use options, i.e. primary waste disposal mission and secondary usefulness; and
(4) multiple waste stream treatment capability.

The U.S. EPA integrated waste management hierarchy suggests finding the proper balance between source reduction, recycling, incineration and land filling; composting is considered a form of recycling (Visalli, 1990). While generally used for comparing solid waste treatment/disposal alternatives, the hierarchy is conceptually applicable to liquid waste streams, although this study makes no attempt to address this. Waste categorization for the Bare Base waste streams is grouped according to primary waste stream applicability, i.e. non-hazardous, hazardous, medical or biohazardous, and wastewater (liquid and solids portions); NBC wastes were considered hazardous. Multiple waste stream applications assess the usefulness of the treatment technology for other or all waste streams, and multiple use options address the applicability of the treatment process for other Bare Base subsystem or civil engineering tasks. Table 8.3.1.1 qualifies these treatment technologies.

Table 8.3.1.1. Qualification of Bare Base Waste Systems Applicabilities

	U.S. EPA Hierarchy	Waste Categorization	Multiple Waste Stream Applications	Multiple Use Options
Land filling	4	Non-hazardous	Potentially	No
Composting	2	Non-hazardous	Potentially	No
Incineration	3	All Solids	Yes	Yes
Plasma Torch	3, 4	All Solids	Yes	No
Lagoon	---	Liquid	No	No
Aerated lagoon	---	Liquid	No	No
Package Systems	---	All Liquid	Yes	No
Treatment Strategies				
Source Reduction	1	All	Yes	Yes
Stream Segregation	2	All	Yes	Yes
Composting Toilets	2	All Liquid	Yes	N/A
Grey water Reuse	2	Liquid	Yes	N/A

Treatment strategies have the greatest applicability across multiple waste streams for all waste streams generated. The concept of source reduction not only impacts waste stream generation, but air lift capacity and costs can be positively affected for numerous subsystems as fuel and other consumables that do not generate a large solid waste stream are minimized. While not directly implied in the waste management hierarchy, stream segregation enhances recovery, reuse and recyclability of all materials.

For all solid waste streams, incineration and plasma torch appear to have the most applicability. While both technologies rank low in the overall waste management hierarchy, mission requirements or operational environments may dictate that these technologies be available. Note that incineration as a technology is not open burning. Both technologies also have multiple use potential; the plasma torch provides greater flexibility for civil engineers.

Incineration and plasma torch technologies can provide energy which is recoverable for heating or steam. The plasma torch, however, can provide expanded civil engineering capabilities, such as runway repair, bridge and construction footings. Additionally, while incineration generates a waste stream that is potentially hazardous, i.e. fly ash, the plasma torch generates vitrified material that can be used for aggregates. For both technologies, air emissions must be addressed.

Technologies which limit the volume of wastewater to be treated will be the most beneficial for Bare Base operations. Composting toilets, or toilets designed to separate liquid and solids from domestic sewage appear most applicable. Note that septic tank systems can enhance these systems in colder operational environments. Separation and recycling of grey water is also advisable.

Separation of wastewater sources will be also potentially important if biological or chemical warfare is conducted in the Bare Base area of operations. Water requirements will increase dramatically, and water sources may be impacted. In arid environments, recycling equipment will be stressed because of filtration requirements.

8.3.2 Quantification of Existing Bare Base Waste Systems Deployment Contingencies

The Bare Base mission, along with the related factors of the deployment duration, the austerity of the location, and the number of humans in the immediate Bare Base area of operation greatly impact the types and volumes of generated wastes. While the operational environment is important with regard to waste storage, treatment, and water usage, the mission and area of operations will most significantly impact the recent Bare Base waste processing practice of using contract vendors or local POTWs.

Table 8.3.2 estimates the variations in sources and volumes of Bare Base wastes generated, based upon deployment contingencies. While not previously quantified, medical or biohazardous and biological/chemical warfare waste streams are listed to address the total wastes generated.

The current Operation Joint Endeavor peacekeeping mission was used as a basis for solid and liquid waste stream generation volumes (section 5.0). Although not quantified or previously estimated, 0.02 lb/person/day of medical wastes was listed (approximately 5% of hazardous waste stream). Biological or chemical wastes resulting from bio/chemical agents were anticipated. Although not included in Table 8.2.3, section 5.3.1 of this report noted that construction waste volumes averaged as high as 358.3 lb/person/day during the initial construction activities during Operation Joint Endeavor.

Table 8.3.2.1. Bare Base Waste Volume Generation Rates Based Upon Deployment Contingencies

	Combat Flight	Humanitarian	Peacekeeping
Solid Waste (lb/capita/day)			
Non-hazardous	6.6	8.8	4.4
Hazardous	1.3	0.8	0.4
Medial/Bio	6.6	2.2	0.02
Liquid Waste (gal/capita/day)			
Liquid	25.0	37.5	12.5
Solid	5.0	7.5	2.5
Bio/Chemical (gal/capita/day)			
Liquid	50.0	Not anticipated	Not anticipated
Solids	25.0	"	"
Total			
Solid Waste (lb/capita/day)	14.5	11.8	4.8
Liquid Waste (gallon/capita/day)	30.0 - 105.5	45.0	15.0-22.3

Humanitarian missions were assumed to potentially double the solid waste and triple the liquid waste volumes as efforts were expanded into the Bare Base area of operations. Note that medical wastes are assumed to be approximately 20% of non-hazardous waste volumes, and hazardous waste volumes were doubled. Although no biological or chemical wastes resulting from bio/chemical agents were anticipated, infectious diseases could contaminate water supplies, requiring additional waste processing. Additionally, construction wastes volumes similar to Operation Joint Endeavor may be generated for a greater duration than Bare Base construction activities. Construction could potentially result in an additional 350 lb/person/day of non-hazardous solid waste for an extended period of time. While these wastes may be reused by the local population, this volume of construction is significant for multiple use waste treatment applications such as incineration and the plasma torch.

Combat flight missions were assumed to be the most taxing regarding waste stream generation for Bare Base operations. Water usage was assumed to increase with activity, therefore associated waste streams volumes were increased. Also, solid waste volumes were anticipated to be two to three times those found during peacekeeping operations. Hazardous waste generation resulting from Bare Base flight line and industrial activities were assumed to

increase three-fold. A significant waste volume increase was anticipated in medical or biohazardous wastes, along with potentially large volumes of wastes associated with decontaminating equipment and personnel after biological or chemical warfare.

8.3.3 Conclusions

While operational environment factors including climate and special tactical considerations impact Bare Base waste processing, all activities, utilities and facilities are impacted by the Bare Base deployment contingency mission and related factors such as the deployment duration, the austerity of the location, and the number of humans in the immediate area of operation. Mission and related factors were estimated to have the greatest impact upon variations in waste volumes.

Peacekeeping missions were assessed as the lowest overall impact upon waste processing systems and were used to estimate the base line waste stream volumes. These missions appear to provide the greatest likelihood that recent Bare Base waste processing practices of using contract vendors or local POTWs could be utilized, if available.

Humanitarian missions are assumed to increase waste volumes generated, although the direct impact upon the Bare Base waste processing systems may not be extensive. If humanitarian activities such as medical care are conducted in the vicinity of the Bare Base, all waste generation, especially biohazardous wastes, will increase. Additionally, given the potential environmental impact of off-site disposal of waste streams, use of Bare Base waste processing systems may be required to ensure environmental stewardship is practiced.

Combat flight operations are assumed to also increase waste generation, but these activities have the most variability regarding waste stream volumes and types. The unknown impacts of medical or biohazardous wastes, coupled with the possibility of biological or chemical warfare, present a potentially dangerous combination of wastes and operational environment. Additionally, the overall importance of the mission greatly reduces the visibility of waste processing as a combat multiplier, therefore the waste processing systems must not detract from the combat flight activities.

9.0 SUMMARY

An evaluation of existing Bare Base waste systems required an assessment of current and preferred practices in concert with equipment and technologies used to process wastes. Current procedures rely upon burial or burning or solid wastes (including non-hazardous, hazardous and medial or biohazardous wastes) and lagoon or septic-tank treatment of liquid wastes. Recent Bare Base operations have elected to discharge all wastewater generated to local Publicly Owned Treatment Works (POTWs) wherever possible or use contract services for water, solid waste and wastewater procurement and disposal, respectively.

This study estimates that 4.4 lbs/person/day of non-hazardous and 0.44 lbs/person/day of hazardous solid waste is generated by an 1100 person Bare Base peacekeeping deployment. Additionally, wastewater generation is estimated to be 14.0 to 22.3 gallons/person/day, with black water liquid and solids, meals and laundry constituting approximately 16.7%, 20.0%, 16.7% and 46.7%, respectively.

The Operation Joint Endeavor peacekeeping mission was used as a basis for solid and liquid waste stream generation volumes (section 5.0). Humanitarian missions are assumed to increase waste volumes generated, although the direct impact upon the Bare Base waste processing systems may not be extensive. Solid waste volumes are estimated to be 11.8 lb/person/day, with liquid wastes volumes of 45.0 gallons/person/day. Of note will be the increased water/wastewater requirements and medical waste in the Bare Base area of operations.

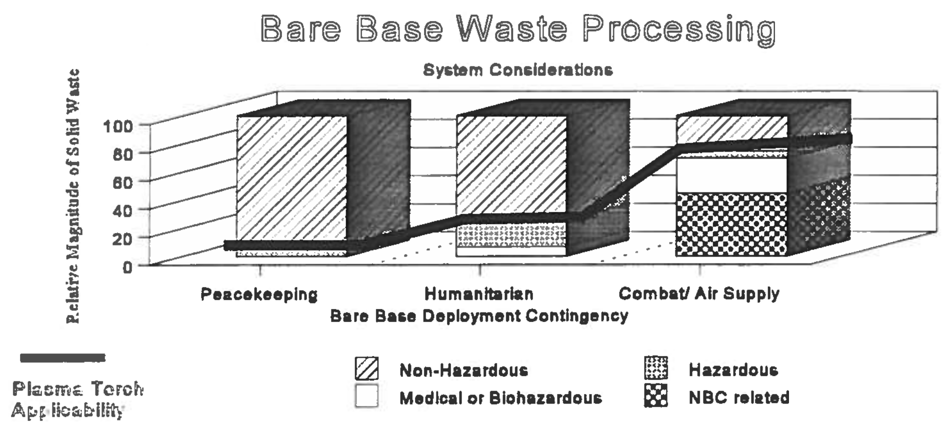
Combat flight operations are also estimated to increase waste generation, but these activities have the most variability regarding waste stream volumes and types. Solid waste volumes are estimated to be 14.5 lb/person/day, with liquid wastes volumes of 30.0 gallons/person/day. Of significant note is the possible tremendous liquid waste volumes resulting from potential biological and/or chemical warfare, and medical or biohazardous wastes.

At a minimum, the Bare Base solid waste processing system should provide: (1) hazardous wastes treatment andstorage during low to no threat scenarios to minimize liability and environmental impacts; and (2) capability to maintain operational effectiveness under all scenarios regarding treatment and/or disposal of municipal solid waste that can potentially impact sanitation. If possible, the Bare Base liquid waste processing system should be designed to use recycling/reuse to ensure that sanitation issues do not impact operational effectiveness.

Figure 9.1 conceptually portrays scenarios that Bare Base deployments may face, along with solid waste generation. While volumes are not quantified, the dependent axis depicts the relative magnitude of the solid waste category. As noted in Table 8.3.2.1, contingency operations will determine the source and volumes of wastes generated. Non-hazardous waste is assumed to generally comprise the largest volume of wastes, but humanitarian or combat situations can result in extensive quantities of materials that must be stored and/or disposed quickly to minimize its overall impact upon operations or human health. Biological/chemical warefare residuals waste were assumed to potentially constitute twice the non-hazardous volume during combat.

A line has been superimposed upon Figure 9.1 to demonstrate the flexibility and diversity of the plasma technology. While a plasma torch is best suited to hazardous, medical or biohazardous, and NBC waste streams not amenable to storage and/or transport, under combat conditions processing non-hazardous waste may be desirable to minimize operational impact.

Figure 9.1. Bare Base Waste Processing System



For all Bare Base solid waste streams, the plasma arc technology appears to have the most applicability for processing non-hazardous, hazardous, medical or biohazardous and/or NBC contaminated wastes. This technology provides the greatest flexibility for the expanding mission requirements and operational environments Bare Base deployments may experience. Plasma arc technology provides a multiple use potential, i.e. expanded peacetime and Bare Base civil engineering capabilities, such as runway repair, bridge and construction footings, and this technology also generates vitrified material that can be used for aggregates.

10.0 CONCLUSIONS

The following conclusions are drawn as a result of this research program:

1. The absence of complete waste generation data from actual deployments required qualification of a large portion of the waste volume estimates.

2. Of special significance, this study found that no reasonable estimate of medical and biohazardous waste generation rates existed, and it was difficult to estimate the nature and quantity of medical wastes generated unless mission criteria were defined.

3. At a minimum, Bare Base waste processing systems should provide (a) treatment and/or storage of hazardous wastes during low to no threat scenarios to minimize liability and environmental impacts; (b) capability to treat and/or dispose of municipal solid waste that can potentially impact sanitation, and thus operational effectiveness; and (c) the ability to stabilize NBC related wastes if needed.

4. The Bare Base liquid waste processing system should be designed to use recycling/reuse to ensure that sanitation issues do not impact operational effectiveness.

5. The plasma arc technology appears to have the most applicability for processing non-hazardous, hazardous, medical or biohazardous, and/or NBC contaminated wastes potentially generated during Bare Base deployment contingencies. This technology also provides a multiple use potential, i.e. in addition to primary waste disposal mission, plasma arc technology has a secondary usefulness for both peacetime and Bare Base activities. In addition to its ability to stabilize all solid waste streams generated in a Bare Base, this technology can provide greater flexibility for civil engineers through runway repair, bridge and construction footings, and aggregate generation.

6. While the operational environment directly impacts Bare Base waste processing system(s) performance, the mission and realted factors (i.e. the deployment duration, the austerity of the location, and the number of humans in the immediate area of operation) will have the greatest impact upon variations in the waste stream volume generation.

7. Peacekeeping missions can be used as a basis for solid and liquid waste stream generation volumes. Humanitarian missions will increase waste volumes generated, although the direct impact upon the Bare Base waste processing systems may not be extensive. Combat flight operations will also increase waste generation, but these activities have the most variability regarding waste stream volumes and types.

11.0 RECOMMENDATIONS FOR FUTURE RESEARCH

Recommendations for future research are as follows:

1. An integrated Bare Base waste processing system that includes plasma arc technology should be more closely examined as a near- and long-term waste processing system for Bare Base deployment contingencies. This system could serve as the basis for a long term study of the Bare Base waste stream and its associated economics. Along with this effort, basic studies should be conducted into the basic phenomenology of the *ex situ* plasma pyrolysis and vitrification process. This would culminate in the development of models to better understand the processes.

2. The solid (non-hazardous, hazardous, and medical or biohazardous) and liquid waste stream generation rates for Bare Base deployment contingencies should be quantified to better develop and design an integrated waste processing system.

3. The treatment capacity of technologies applicable to domestic waste such as composting toilets and waste separation systems should be addressed as part of a larger waste processing strategy. These technologies hold promise for a wide range of environmental conditions and operational scenarios. Also, these technologies may be applicable to peacetime operations at isolated locations.

4. Because Phase II of this study addresses waste reduction methods and practices, examining the benefits of source reduction strategies for reducing construction waste volumes builds upon knowledge derived from this study. Operation Joint Endeavor illustrated that large volumes of construction wastes are generated, and applied research focused on improving practices to reduce waste before construction will greatly impact airlift capacity and minimize waste generation.

5. Develop plasma arc technologies for civil engineer applications and experience for runway repair, construction footings and aggregate generation.

6. Additionally, the promising capability of plasma arc technology for the *in situ* remediation at Air Force facilities, should be examined. This demonstration would expand the usefulness of plasma technologies under non-Bare Base scenarios and improve the overall economics of the system.

12.0 BIBLIOGRAPHY

AFPAM 10-219 *Guide for Bare Base Planning*

Casio, J. (1997). "ISO 14000: A New Approach to Environmental Protection," *23rd Environmental Symposium and Exhibition*, American Defense Preparedness Association/ National Security Industrial Association, pp. 572-578.

Circeo, L., Nemeth, J. and Newsom, R., (1997). *Final Report, Evaluation of Plasma Arc Technology for the Treatment of Municipal Solid Wastes in Georgia*, Georgia Institute of Technology, School of Architecture Construction Research Center, Atlanta, Georgia.

Grosskopf, K. and Circeo, L., (1997). "Development of an Air Force Bare Base Waste Processing System," prepared for Tyndall AFB.

Jenkins, N. L., and Gregory, R. , (1996). *A Study of Waste Removal Processes for a Bare Base*, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, Georgia.

McGhin, R.F., (1997). "Environmental Finding of Suitability to Test," *23rd Environmental Symposium and Exhibition*, American Defense Preparedness Association/ National Security Industrial Association, pp. 47-52.

Metcalf & Eddy, Inc., (1991). *Wastewater Engineering: Treatment, Disposal, and Reuse Third Edition*, revised by Tchobanoglous, G. and Burton, F. L., McGraw-Hill, Inc., New York, New York.

Ontario Ministry of Energy, (1992). *Project Summary: Plasma Gasification Could Set New Standard for Municipal Solid Waste Disposal*, EverSearch Program Office, Toronto, Ontario, Canada.

Riggle, D., (1996). "Technology Improves for Composting Toilets," *Biocycle*, *37*, *4*, pp. 39-43.

Sverdrup Technology, Inc., (1996). *Bare Base Infrastructure Road Map: Report On The Bare Base Study Phases I And II*, Eglin AFB, Florida.

Tchobanoglous, G., Theisen, H., and Eliassen, R., (1977). *Solid Wastes: Engineering Principles and Management Issues*, McGraw-Hill, Inc., New York, New York.

U.S. Environmental Protection Agency, (1995). *Characterization of Municipal Solid Waste in the United States: 1995 Update*, Office of Solid Waste, Washington, District of Columbia.

U.S. Environmental Protection Agency, (1995b). *Environmental, Economic and Energy Impacts*

of Material Recovery Facilities: A MITE Program Evaluation, Office of Solid Waste, Washington, District of Columbia.

U.S. Environmental Protection Agency, (1995c). *Household Hazardous Waste Characterization Study for Palm Beach County, Florida: A MITE Program Evaluation*, Office of Solid Waste, Washington, District of Columbia.

Visalli, J. R., (1990). "The Similarity Of Environmental Impacts From All Methods Of Managing Solid Wastes," *Journal of Environmental Systems, 19(2)*, pp. 155-170.